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ABSTRACT

Drawing from research and observations at Lansing Community College (Michigan) (LCC), this paper argues that typical arithmetic courses do little to prepare students to master algebra, and proposes an alternative set of arithmetic skills as actual prerequisites to algebra. The first section offers a description of the algebra sequence at LCC, which consists of Pre-Algebra (MTH 009), Beginning Algebra (MTH 012), and Intermediate Algebra. Next, data on LCC students' arithmetic test scores and MTH 012 success rates are examined, considering the relationships among test scores, success rates, previous high school algebra, and knowledge of specific items on the arithmetic placement test and MTH 012 success. The next section summarizes a number of other research studies that examined predictor variables for and influences on success in algebra. Next, a rationale is presented for awarding algebra prerequisite status to four arithmetic skills: understanding the meaning of symbols used in arithmetic; understanding basic properties of numbers, especially fractions; using the order of operations agreement; and understanding some of the structure behind solving applications. Concluding comments indicate that the best predictors of readiness for beginning algebra are having had prior algebra, grade received in last math class; and score on a test of arithmetic skills, while warning that completion of an arithmetic course appears to offer no advantage in the study of beginning algebra for a large body of students. (JMC)

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ARITHMETIC: PREREQUISITE TO ALGEBRA?

Jack W. Rotman
Lansing Community College
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INTRODUCTION

A common practice at colleges is to list an arithmetic course as the prerequisite to the first algebra course. The implication is that the skills in the arithmetic course are needed before the student is ready to master the skills in the algebra course. It is my contention that, in most situations, this statement is false. In this presentation, I wish to present some research which helps frame our discussion, and to present a brief catalog of arithmetic skills which might be better candidates for a prerequisite to algebra.

RESEARCH (OBSERVATIONS) -- From Lansing Community College

The basic motivation for my exploration of this topic comes from anecdotal evidence from my students in beginning algebra. Whenever a student was having difficulty with the material in algebra, instructors would suggest that the student take our "pre-algebra" course. As a general observation, I noticed that when such students came back to algebra, they had essentially the same difficulties as they did the first time. What good does an arithmetic course do to prepare a student for algebra?

In this section, I will present some data on our situation at LCC as it relates to this question, and then report on some research in the next section that appears to have a bearing.

Lansing Community College offers a typical beginning algebra course (MTH 012) which covers the usual assortment of basic skills with expressions, equations, and word problems. The delivery system used is somewhat unusual, in that most students take the course in our Mathematics Laboratory; this program uses self-study along with a competency-based testing system, in which the main instructional contact is one-to-one assistance with an instructor. The prerequisite to MTH 012 is Pre-Algebra (MTH 009), which is offered in the same formats. The subsequent course to MTH 012 is Intermediate Algebra (MTH 102).

The content of MTH 009 is outlined here:

Test 1	Whole Numbers
Test 2	Fractions
Test 3	Decimals
Test 4	Ratio and Proportion
Test 5	Percents
Test 6	Applications (Consumer, Business)
Test 7	Statistics and Measurements
Test 8	Geometry
Test 9	Signed Numbers
Test 10	Basic Algebra

Currently, we use Aufmann and Barker's text for MTH 009; prior to 1984, we used Keedy and Bittinger's text, with very similar content. From contact with other colleges and textbooks, I believe that the content of our course is very typical of that found in a college developmental arithmetic course.

Part of the developmental mathematics program at LCC is the computerized record system. As a result of this system, we get routine files containing student course information as well as historical information about prior courses. The data presented in the following tables is the result of using these files over a period of 2 years.

Students are placed into MTH 012 (Beginning Algebra) in two major ways: Either they have passed MTH 009, or they take the Algebra Placement Test. Some of these latter students also have an Arithmetic Placement Test score, and a few are placed into MTH 012 based on their Arithmetic Test score only. The Arithmetic Test is primarily used to determine placement into MTH 009. The first table examines the relationship between scores on the Arithmetic Test, having MTH 009, and success rates in MTH 012.

TABLE I MTH 012 Success Rates by Arithmetic Test Scores

Arithmetic Score	Previous LCC MTH	Percent Success[1]	Number
1 - 25	Had MTH 009	55%	289
	No LCC MTH	33	24
26 - 31	Had MTH 009	66	249
	No LCC MTH	65	81
32 - 34	Had MTH 009	79	28
	No LCC MTH	71	49

The patterns in Table 1 suggest that only those students who score below 26 have significantly improved success rates in MTH 012 after completing MTH 009; students who score at least 26 have very similar success rates in MTH 012, whether they passed MTH 009 or not. One might also conclude that the Arithmetic Test is measuring some skills that are related to success in Beginning Algebra, since the success rates differ significantly between the three score levels.

The next table (on page 3) explores the interaction between prior algebra (high school) and passing MTH 009, as it relates to Beginning Algebra success. Students fill out a brief information sheet at the start of each of our courses; the data below is based on self-reports on this form concerning whether the student had taken algebra in high school.

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[1] For this purpose, "success" is passing MTH 012 with a 2.0 or better, or earning an Incomplete with at least 80% of the course passed.

TABLE II MTH 012 Success Rates by Prior Algebra

LCC MTH history	Percent Success	Number
No Prior Algebra (High School)		
Had MTH 009	51%	203
No LCC MTH	52	31
Had Prior Algebra (High School)		
Had MTH 009	67	465
No LCC MTH	74	720

The data presented in Table 2 shows a definite consistency in the "No Prior Algebra" groups; regardless of whether they took MTH 009, they performed at about the same level in MTH 012. For the students who had prior algebra, those who took MTH 009 prior to MTH 012 did not succeed as well as those who went directly in to MTH 012. The differences between the prior algebra groups is very significant, and outweighs any possible benefit of taking MTH 009 prior to MTH 012. Taken with the data in the first table, one would suspect that students who had prior algebra scored higher on the Arithmetic Test than those who did not have prior algebra; it would be difficult to determine which factor is stronger: prior algebra or score on the Arithmetic Test.

Since the first two tables suggest that taking MTH 009 does not prepare all students for MTH 012, we might further question which students benefit from taking MTH 009 first. A logical question deals with how well the student performed in the MTH 009 course.

TABLE III MTH 012 Success Rates by MTH 009 Grade

MTH 009 Grade	Percent Success in MTH 012
2.0	29%
2.5	34
3.0	48
3.5	64
4.0	78

Only those students who earned at least a 3.5 in MTH 009 performed at a comparable level to those who placed directly into MTH 012. Overall, these three tables suggest that passing MTH 009 is not a positive indicator of readiness for beginning algebra; the level of grade received appears to be a stronger predictor. (This is consistent with some research that I will cite later.)

The data presented so far might also raise questions about how students are placed into their initial course at LCC. Lansing Community College uses placement tests based on the MAA Placement Test program. The Placement Tests of interest here are the Arithmetic Test (34 items) and the Algebra Test (37 items); the Algebra Test actually starts with about 18 questions on topics from our Pre-Algebra course. The cutoffs in use were established based on giving the Placement Test to students completing the prerequisite course. In this case, we

place students into Beginning Algebra with a score of 14 to 24 on the Algebra Test, and we suggest Beginning Algebra if they score 32 to 34 on the Arithmetic. Normally, a student takes only one of these two Placement Tests; however, we have had a number of students take both tests, which allows some comparison of the two tests.

TABLE IV Correlation Between Arithmetic and Algebra Placement Test Scores

n	230[2]	
Correlation	.54	$r^2 = .29$
Slope	.40	Intercept = 21 (Arithmetic)

The moderate correlation shown here is not helpful for placement or prediction purposes; it is not unusual for the results of the two Tests to be contradictory. For example, the predicted Arithmetic Score based on the Algebra Score needed for placement into MTH 102 (Intermediate Algebra) places a student into MTH 009 or 012. Not only is this predicted by the regression equation, but it happens at a significant rate in practice.

We also can examine possible relationships between Placement Test scores and MTH 012 performance indicators for students who did not take MTH 009 before MTH 012.

TABLE V Correlations Between Placement Test Scores and MTH 012 Performance

	Tests Passed[3]	Average Score	Number
Arithmetic Score	.20	.36	130
Algebra Score	.19	.19	677

When a regression analysis is done on this data, neither test score correlates significantly with the number of tests passed in MTH 012; the Arithmetic Score does correlate significantly with the average MTH 012 test score, but the sample size is somewhat small and not random. Again, the Arithmetic Test seems to measure <u>something</u> that is <u>somewhat</u> associated with success in MTH 012, but the relationship is not particularly strong compared to other factors such as whether the student had prior algebra.

Since there is not a general correlation between the Algebra Test and MTH 012 performance, and we have a large sample, we can explore whether there are

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[2] This sample is not random or complete, so the results should be treated with caution.

[3] Beginning Algebra has 10 Tests, with a maximum score of 100. Students need at least a 75 score to pass. The average score includes only the passed tests.

groups of items (factors) on the Algebra Test which would correlate better with MTH 012 performance. In the case of Form A of the Algebra Test, there were 5 factors separated by the SPSS package; one of these was related to the number of tests passed in MTH 012.

TABLE VI Algebra (Form A) Items in Factor Group Related to MTH 012 Performance

Multiply 3 proper fractions, and reduce.
Multiply 3 decimals (such as 0.5 • 0.5 • 0.5).
Add 2 proper fractions with different denominators.
Substitute a value into a formula and calculate (no solving).
Find the fourth power of a whole number.
Subtract two mixed numbers (involving borrowing).
Solve problem involving sales tax (tax known, base unknown).

number of students in sample: 265

For our purposes, we can not reach many conclusions from this relationship; the exact same kind of items are present on Form B of the Test, but they were not found to be related to performance in MTH 012.

We could, in theory, conduct the comparable factor analysis on the Arithmetic Test and compare those factors to Beginning Algebra performance. However, there were only 130 students in the period who have Arithmetic Test scores and did <u>not</u> take MTH 009 prior to MTH 012. The process to match these 130 records of MTH 012 performance with their detailed placement test records is not perfect, so the actual sample available for the analysis is less than 60 per form of the Arithmetic Test.

Having gone through the above tables and comments, we have reached a inconclusive end-point. There appears to be some connection between <u>some</u> arithmetic skills and performance in algebra, but the data is not convincing. I have searched for other studies of this area; most citations dealt with how to use arithmetic in teaching algebra, or how to use algebraic properties in teaching arithmetic. Most studies did not deal with whether arithmetic skills had any bearing on success in algebra. Below, the ones that did focus on the relationship between arithmetic skills and algebra performance.

RESEARCH — From Other Sources

Deborah Levine (1990) reported that MAT 001 (Preparatory Mathematics) students had MAT 002 (Introductory Algebra) pass rates similar to those of other students.

Attia Elgammal (1987) examined variables for prediction of success in high school Algebra I; in this study, the variables were:

Previous year (grade) math mark;
Michigan Educational Assessment Program (MEAP) Test score;
Orleans-Hanna Algebra Prognosis Test;
Attitude Scale (Aiken-Dreger);

Study Habits Scale (Brown-Holtzman).

The best simple correlations with algebra performance were the previous math grade and the MEAP score, in that order.

Ruth Bloland and William Michael (1984) conducted a similar study, using these variables:

Age;
Orleans-Hanna Algebra Prognosis Test;
Reasoning Scale -- concrete versus formal (Arlin Test of Formal Reasoning);
Iowa Tests of Basic Skills -- subtests on:
- Reading;
- Vocabulary;
- Arithmetic Concepts;
- Arithmetic Problem Solving;
- Arithmetic Computations

The best simple correlations were Arithmetic Concepts, Age, Arithmetic Computation, and the Orleans-Hanna test.

William Palow (1988) presented a review of research on this question. He makes the following citations:

L. M. Siglin (1978) — 8th grade performance best predictor for high school algebra.

L. A. A. B. Gray (1977) -- High school grades in General Math and Business Math have no significant relationship to success in college algebra.

R. M. Clark (1982) — High school math grades "had no bearing" on the ability to succeed in beginning algebra at a community college.

P. Malinen (1971) — "importance of numerical ability in predicting ability in algebra was insignificant."

Palow also reported data from his own study; the score on a 10-item Arithmetic Pretest was not related significantly to performance on a 40-item final on "computational" beginning algebra.

Steve Sworder (1990) presented a review of the assessment program at Saddleback College (CA), which includes an "Algebra Readiness" test. The scores on this test were compared to performance in their Beginning Algebra course; students who received a grade of C or higher were counted as successful, while all others were classified as non-successful. The results are summarized below.

TABLE VII Performance in Saddleback College Beginning Algebra by "Algebra Readiness" Score

score	number	% Success	% Non-Success
1 to 25	88	22%	78%
26 to 50	236	41%	59%

Sworder states that the cutoff (26) could not be improved upon, because the scores for the non-successful students ranged so high. One observation I would

add is that it is not until scores of 37 that the success rate is 50% or higher. (These success rates are lower than typical because of the total inclusion of drops in the non-success category; often, drops are excluded entirely.) The data is somewhat difficult to interpret for the present purposes because the specific types of items on the readiness test were not described.

Berenson, et al (1990) conducted research into the effect of Piagetian stages of development within the beginning algebra classroom at college. The variables considered were:

Group Assessment of Logical Thinking (developmental levels);
SAT-Verbal score;
SAT-Mathematics score;
Algebra placement test score;
Trigonometry placement test score;
High school grade point average

They found that the developmental level did not produce a significant correlation with the grade received for the course; high school grade point average was the best single predictor, followed by the score on the university algebra placement test. Two facts limit the applicability of this study: the population did not include any students with a high school GPA below 2.0 (the average GPA was about 3), and the criterion variable was the final grade -- it would have been more powerful to have a final exam score as the criterion. Even though the sample they used had higher high school GPA's than present at many community colleges, only 42% tested at the formal level of reasoning.

In interpreting these studies, care is needed. Often, the sample size is very small, and there is not thorough experimental control. Nevertheless, there are indications that there:

a) is some relationship between some arithmetic skills (as measured by a test) and algebra performance.
b) is no consistent relationship between prior math grades and algebra performance; recent grades seem to be more related.

The remainder of the presentation will deal with <u>which</u> arithmetic skills are important for algebra. Since no research was found that deals with this level of detail, what follows will be based on some hypotheses and practical experience.

A POSITION STATEMENT

It is my contention that these features of arithmetic skills reflect their prerequisite status with respect to learning algebra:

1) Understanding the meaning of symbols used in arithmetic.

2) Understanding basic properties of numbers, especially fractions.

3) Using the order of operations agreement.

4) Understanding some of the structure behind solving applications.

Before listing some specific arithmetic skills, I will elaborate briefly on each of these criteria.

1) Understanding the meaning of symbols used in arithmetic.

For a number of reasons, students need to know the meaning of the symbols used in arithmetic -- even more than knowing how to manipulate them. Students need to know that juxtaposition means addition in arithmetic — such as in whole number place value and in mixed numbers; in algebra, we make a point of saying that 5a means a product, and students need to be clear that the rules are changing. Related to this criteria is the goal of developing a number sense. The examples below should help clarify these points.

2) Understanding basic properties of numbers, especially fractions.

Fraction concepts deserve to be singled out, because algebra typically uses fractional notation to indicate a quotient. In particular, students need to know that a fraction must contain one term in each the numerator and denominator before reducing; it would be nice if the exception was also understood (the denominator is a divisor of all terms in the numerator, or vice versa).

3) Using the order of operations agreement.

The order of operations agreement provides a number of ways to prepare students for algebra while studying. In particular, students must understand that products are found before sums (or differences) -- unless parentheses enclose the sum. If students are introduced to the special cases like $5(8 - 2)$ using a distributive property, that would be nice; however, I do not think this is strictly required.

4) Understanding some of the structure behind solving applications.

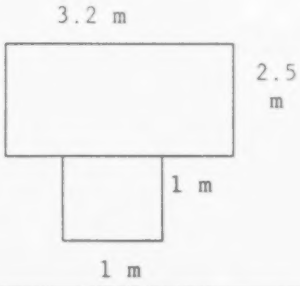
When we speak of solving applications, we often are especially interested in the structure of the solution. In algebra, this structure must be stated explicitly to solve almost all applications considered. Students need to be able to analyze the problem and generate an explicit solution method; even more important, they need to be able to label the numbers used and found.

In many ways, these goals are a result of taking a "constructivist" view of learning mathematics. (See the references by Davis; Schoenfeld.) In addition, they respond to observations made by researchers that students do not attach the same meaning to symbols that we (as experts) do. (See the references by Matz; Rosnick and Clement.) A basic premise for what follows is this: The foundation for understanding and misunderstanding algebra is laid in the arithmetic experiences that students encounter before they reach an algebra course; it is this understanding that is a prerequisite to algebra, not any specific set of computational skills

To state it in a more direct manner: Students will assume that algebraic objects that "look like" those previously encountered will follow the same rules as those used before. In general, most students are not exposed to the fullness of arithmetic; the general case is not presented. The course involves mastering specific skills that can be used only if the numbers are presented in a certain form, and when only certain words are used in the "word problems". Limiting arithmetic to simple cases provides ample opportunity for students to make erroneous generalizations. For further information and thorough discussion of the related theories and issues, see those sources cited in the bibliography.

SPECIFIC ARITHMETIC SKILLS THAT ARE PREREQUISITE TO ALGEBRA

As a consequence of my belief in the ideas of the prior sections, specific examples will be presented here.

Is NOT prerequisite to algebra	IS prerequisite to algebra	A rationale
add $\frac{5}{12}$ *and* $\frac{3}{8}$	the sum of $\frac{5}{12}$ *and* $\frac{3}{8}$ is about ____	Develops number sense
multiply 2.5 and 3.2	How much will it cost, to carpet the rooms below if carpeting costs $4.85 per square meter? 	encourages analyzing complex problem into parts, and interpreting information.
A student's reading speed increased 70 words per minute from 280 words per minute. What is the percent increase in reading speed?	A student's reading speed increased 70 words per minute from 280 words per minute. Write the rate of increase as both a fraction and a percent.	Encourages understanding the symbols.
Write 0.28 as a percent.	The price of a car has risen 28% in the last 4 years, from a value of $14,000 to $17,920. Write two equations based on this information.	The context of percents is emphasized (meaning of symbols); structure of application is stressed.
Sara received a 4.5% increase in salary. If her salary was $24,000 before the raise, was is the increase in salary?	Sara received a 4.5% increase in salary. If her salary was $24,000 before the raise, was is her new salary?	Structure of application is emphasized — what the numbers represent.
Reduce $\frac{7}{2}$ and write as a mixed number.	Reduce $\frac{3+4}{2}$	Emphasizes fraction concepts; de-emphasizes rote conversions.

Is NOT prerequisite to algebra	IS prerequisite to algebra	A rationale
Simplify $\frac{18}{3}$	Find $\frac{18}{0}$	Deals with 2 important ideas: 1) Fraction shows division. 2) Division by 0 is not defined. Also, avoids mechanical processes.
Find the perimeter of a rectangle whose width is 12 feet and whose length is 18 feet.	In the formula $P = 2L + 2W$ what does the "W" stand for?	Deals with knowing the difference between a label and a place-holder (variable). Correct answer is "length of the width (in feet or whatever)".
Change $3\frac{1}{2}$ as an improper fraction	Write $3\frac{1}{2}$ as a sum.	Focuses on the meaning of the symbols.
3 cups of flour are needed for each 5 pounds of sugar in a recipe. How much flour is needed for 18 pounds of sugar?	3 cups of flour are needed for each 5 pounds of sugar in a recipe, but we need to use 18 pounds of sugar. Write a proportion that could be used to solve this.	The answer should include the "=" sign, which plays a different purpose here than in $4 + 11 = ?$
If Joe makes $5.60 per hour, how much does he make in 8.25 hours?	If we multiply a wage (dollars per hour) times the number of hours, what do we get?	Focuses on understanding the structure of the problem.
Eggs are to be packed in cartons, each holding 12 eggs. If there are 168 eggs, how many cartons can be filled?	Eggs are to be packed in cartons, each holding 12 eggs. If there are 147 eggs and as many cartons are filled as possible, how many eggs are left over?	Focuses on understanding the structure of the problem.
A company has 20 boxes of paper in stock. It then sends out 2 shipments of 6 boxes each. How many are left?	Find $20 - 6(2)$	Prepares students for $20 - 6x$: order of operations. Application is too basic be of value in preparation for algebra.

Is NOT prerequisite to algebra	IS prerequisite to algebra	A rationale
Find the negative of -5	Find the opposite of -5	More precise language mastery; emphasizes consistent meaning of symbols
Find 8.5 - 12.3	Subtract 12.3 from 8.5	Connects words and symbols to find answer.

CONCLUSION

The available data suggests that the best predictors of readiness for learning beginning algebra among adults are:

1) Having had prior algebra (such as in high school).

2) Grade received in last math class (most recent—high school or college).

3) Score on a test of arithmetic skills.

Thus, instruction on some arithmetic skills helps prepare students for algebra for some students. However, the 3 factors are not independent; there is a large body of students for whom completion of an arithmetic course appears to offer no advantage in their study of beginning algebra. We are still left with the question of why we should teach arithmetic to adults as a means prepare them for algebra. And, even if we should teach arithmetic to such students, which arithmetic skills are important for this purpose?

Further research could settle the question. We should make use of learning theories to guide us until definite answers can be found. In addition, we can examine the common difficulties that students encounter in algebra with an eye towards what effect our arithmetic instruction has had on them. Too often, algebra forces students to unlearn arithmetic knowledge that had limited value anyway.

However we might respond to these challenges, whether in agreement or not, our students will be helped greatly in algebra if we question how they were exposed to arithmetic.

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